AD-A067 861 NAVAL SURFACE WEAPONS CENTER DAHLGREN LAB VA F/G 8/7
POLAR MOTION THROUGH 1977 FROM DOPPLER SATELLITE OBSERVATIONS.(U)
FEB 79 C OESTERWINTER

UNCLASSIFIED NSWC/DL/TR-3935 NL

| OF |
AD
A067 861

END
DATE
FILMED
6-79
DDC

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) NSWC/DL/TR-3935	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) POLAR MOTION THROUGH 1977 FROM DOPPLER SATELLITE OBSERVATIONS.		5. TYPE OF REPORT & PERIOD COVERED (9) Final Rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Claus Oesterwinter		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Surface Weapons Center (K10) Dahlgren Laboratory Dahlgren, Virginia 22448		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS HM0027-79-C006
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Surface Weapons Center Dahlgren Laboratory Dahlgren, Virginia 22448		12. REPORT DATE (11) Feb[redacted]79
		13. NUMBER OF PAGES 34
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 33p.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Polar motion
Doppler satellite observations

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Doppler observations of Navy navigation satellites have been used to compute pole positions on a daily basis since 1969. Limited results exist for the period 1964 to 1969. Based on Doppler observations from four or five satellites, the standard error for a five-day mean pole position is less than 20 cm. Comparisons are made between BIH, IPMS, and ILS results and those obtained from Doppler. It is shown that the six years of reliable Doppler data from 1972 on contribute little in finding the Chandler period.

CONT'

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

391598

16

20. Abstract (Continued)

plus or minus

Using observations from the three astronomical sources over 12 years yields a Chandler period of 432.0 ± 0.2 days.

FOREWORD

The Defense Mapping Agency Topographic Center continued to perform the orbit computations of the Navy Navigational Satellites (NAVSAT) and to derive the two-day pole coordinate solutions upon which this report is based.

Subsequent computations and analysis were performed in the Astronautics and Geodesy Division of the Strategic Systems Department. Mrs. Jan H. Bruce did many of the calculations, all computer runs, and the plotting of results.

The material contained in this report was first presented at the International Astronomical Union Symposium No. 82, "Time and the Earth's Rotation," Cadiz, Spain, 8-12 May 1978.

Released By:

R. A. NIEMANN, Head
Strategic Systems Department

TABLE OF CONTENTS

	Page
PREVIOUS WORK	1
OBSERVATIONS AND DATA REDUCTIONS	1
DOPPLER POLE POSITIONING ACCURACY	3
RESULTS 1974-1977	4
TABULATION OF DOPPLER RESULTS	4
POLE COORDINATE PLOTS	5
DIFFERENCES IN POLE COORDINATES	13
THE CHANDLER PERIOD	13
ADVANTAGES AND DISADVANTAGES OF DOPPLER	20
FUTURE PLANS	20
SUMMARY	20
REFERENCES	21
DISTRIBUTION	

LIST OF ILLUSTRATIONS

Figure		Page
1	1974 Pole Path	6
2	1975 Pole Path	7
3	1976 Pole Path	7
4	1977 Pole Path	8
5	1977 Pole Path	8
6	Pole Position for 1974, X Component	9
7	Pole Position for 1975, X Component	9
8	Pole Position for 1976, X Component	10
9	Pole Position for 1977, X Component	10
10	Pole Position for 1974, Y Component	11
11	Pole Position for 1975, Y Component	11
12	Pole Position for 1976, Y Component	12
13	Pole Position for 1977, Y Component	12
14	Difference in X Component of Pole Position 1974-1977	14
15	Difference in Y Component of Pole Position 1974-1977	15
16	Residuals after 5-Parameter Fit X Component	18
17	Residuals after 5-Parameter Fit Y Component	18

LIST OF TABLES

Table		Page
1	Available Doppler Satellite Data (Day Numbers)	2
2	Preliminary Yearly RMS of Standard Deviations and Errors	3
3	Dahlgren Polar Monitoring Service	5
4	Average Differences in Pole Position By Year	16
5	Coordinate Systems and Gravity Fields	17
6	Chandler Period	19
7	Bowman/Leroy Spectral Analysis	19

PREVIOUS WORK

The determination of the coordinates (X and Y) of the earth's spin axis from Doppler observation has been described by Anderle and his colleagues in a series of publications and reports.

The method of computation was briefly explained by Anderle and Beuglass (1970). A more detailed description of the observational procedures, the data reduction techniques, and error sources was given by Anderle (1973a).

Results of Doppler data analysis and comparison with other determinations are discussed in numerous places. All Doppler results are based on five-day mean values of X and Y. They are tabulated and discussed for 1969 by Anderle and Beuglass (1970); for 1967 to 1970 by Anderle (1970); for 1969 to 1971 by Anderle (1972); for 1972 by Anderle (1973b); and for 1973 by Beuglass (1974). The five-day means for the years 1974 to 1977 are given in this report. A few two-day solutions for 1964 to 1969 may be found in Anderle (1973b), Appendix F.

The above data are normally shown as plots of X versus time, Y versus time, and X versus Y. They are given by Anderle and Beuglass (1970) for 1969; by Anderle (1970) for 1967, 1968, 1969 and 1970; by Beuglass and Anderle (1972) for 1970; by Anderle (1972) for 1969, 1970, and 1971; by Anderle (1973b) for the period 1964 through 1967 and for 1972; by Anderle (1973a) for mid-1971 to mid-1972; by Beuglass (1974) for 1973; and by Anderle (1976b) for 1975. Plots for the years 1974 to 1977 are shown in this report.

Anderle (1976a) has also compared Doppler derived pole coordinates with classical optical solutions. He plots the differences BIH-ILS,* DMA (Doppler) -BIH,** and DMA-ILS for the span 1964 to 1975. He also tabulates yearly mean values for above differences as well as associated statistics. Anderle (1976b) adds the comparison DMA-IPMS† and shows more detail by breaking the plots into two spans, 1964 through 1969 and 1970 to 1975.

OBSERVATIONS AND DATA REDUCTIONS

The following is a very brief description of observational data and their analyses. Details may be found in the references listed at the end of this report, especially in Anderle (1973a) and (1976b).

Observations are the Doppler shifts in the continuous radio frequencies at 150 and 400 MHz transmitted by the U. S. Navigation System satellites

---

* BIH-ILS is Bureau International de L'Heure-International Latitude Service
** DMA-BIH is Defense Mapping Agency-Bureau International de L'Heure
† DMA-IPMS is Defense Mapping Agency-International Polar Motion Service

(Kershner, 1967). Analog combination of these two frequencies permits elimination of one large error source; namely, the first-order ionospheric refraction effect.

The number of satellites being observed varies between two and five, depending on Navy requirements. Table 1 shows which satellites were observed, and when, for the years 1974 to 1977.

Table 1. Available Doppler Satellite Data
(Day Numbers)

	Satellites				
	1967-34A	1967-48A	1967-92A	1970-67A	1973-81A
1974		166-280	1-87	89-363	
1975				2-362	13-363
1976	155-365			6-364	1-157
1977	7-167	21-167	21-167	6-364	21-365

Observations are taken by as many ground stations as are operational. They increased in number from about 13 in 1969 (Anderle and Beuglass, 1970) to about 20 in recent years (Anderle, 1976b).

All observations taken during a 48-hr time span are used in a least-squares solution to improve, primarily, the orbital parameters. During this process, the satellite orbits are numerically integrated by Cowell's method, that is, the Gauss-Jackson algorithm applied to the differential equations in the rectangular accelerations. The program is normally run with a 60-sec integration step size and order 12. The reference frame is the mean equator and equinox at the beginning of the observation span. The mathematical model contains about 480 gravity terms, atmospheric drag, radiation pressure, luni-solar solid earth tides, with the Love number presently set at 0.26. The force field is complete enough to permit determination of the satellite's position good to about 1 m.

The solution also contains, among other parameters, the coordinates X and Y of the spin axis, referred to the Conventional International Origin (CIO). Such two-day solutions are obtained separately for each satellite. Subsequently, all two-day solutions from up to five different satellites are combined into five-day means. The latter is published by the U. S. Naval Observatory in "Preliminary Times and Coordinates of the Pole, Series 7."

The computation of pole positions based on Doppler observations originated at the Naval Weapons Laboratory (now the Naval Surface Weapons Center (NSWC)). In April 1975, the responsibility of computing Navy navigational satellite (NAVSAT) orbit, and, hence, the derivation of pole positions was transferred to the Topographic Center of the Defense Mapping Agency (DMATC). Since DMATC employs the same computer programs, the transfer did not affect position results.

Over the years, there have been a number of changes in the observation station network and observation techniques (Anderle, 1973a) as well as improvements in the data reduction methods (Anderle, 1972). However, the procedures have been essentially the same since August, 1971, so that Doppler results after this date are believed to be homogeneous.

DOPPLER POLE POSITIONING ACCURACY

The formal standard deviation for the polar coordinates from a two-day solution is about 5 cm during the second half of 1977. But it must be remembered that such solutions are made for each satellite separately. All two-day solutions are then combined into five-day means. Subsequently, one can compute the more realistic standard deviation of a two-day coordinate with respect to the five-day mean. That number is presently a bit less than 40 cm. The standard deviation of the five-day mean itself (standard error) has been just under 20 cm for the last two years.

The increase in accuracy from 1967 to 1977 is shown in Table 2. However, the data before and after 1972 are not immediately comparable. Polar coordinates until August 1971 were obtained using the tangential component of the station navigations only, and they were one-day solutions. Moreover, they were computed after orbit improvement, not in a simultaneous least-squares solution.

Table 2. Preliminary Yearly RMS of Standard Deviations and Errors

	Standard Deviations (m) (two-day solutions*)			Standard Errors (m) (five-day means)		
	X	Y	Av.	X	Y	Av.
1967	1.65	1.78	1.72	0.89	0.74	0.82
1968	1.48	1.60	1.54	0.86	0.93	0.90
1969	1.51	1.27	1.40	0.69	0.60	0.65
1970	1.25	1.15	1.20	0.57	0.53	0.55
1971	1.16	1.39	1.28	0.52	0.62	0.57
1972	0.75	0.69	0.72	0.37	0.32	0.35
1973	0.38	0.44	0.41	0.22	0.28	0.25
1974	0.48	0.50	0.49	0.30	0.32	0.31
1975	0.47	0.36	0.42	0.22	0.18	0.20
1976	0.40	0.30	0.35	0.20	0.15	0.18
1977	0.41	0.34	0.38	0.18	0.15	0.17

*One-day solutions before 1972

Anderle (1973a) pointed out that the principal error source in Doppler polar coordinates is due to inadequate knowledge of the earth gravity field. Despite recent advances, this remains true today.

RESULTS 1974-1977

Anderle and his colleagues have already published diagrams and tables summarizing polar motion during 1974 and 1975. Since some of their results were based on preliminary data, they are repeated here using final data. Final values were also available for 1976 while some 1977 results are still preliminary. They will be identified as such below.

TABULATION OF DOPPLER RESULTS

Table 3 is a sample containing the two- and five-day Doppler solutions for polar coordinates. The complete tables for the years 1974 to 1977 will be published in a forthcoming NSWC report. The first two columns show the day numbers for each two-day solution. They are followed by X and Y and their formal standard deviations (labelled "Standard Error") as obtained from the covariance matrix of the least-squares solution. The last two columns are the satellite designation and the nominal value for UTC-UT1. The latter information is not used in our pole-position calculations.

In the last three lines of each block, only the first three columns are of interest. The first column shows the day number for which the five-day average is being computed. Columns two and three show the weighted averages for X and Y, where the weight is taken as $1/\sigma^2$, σ being the two-day standard deviations mentioned above. The line marked STD DEV is the weighted standard deviation of a two-day solution with respect to the five-day mean. The last line, labelled STD ERR, is the previous line divided by the square root of n. It is, therefore, the standard deviation of the five-day mean.

Note that the program is presently limited to include only the first four two-day solutions for any given day in the five-day means, even though all available two-day results are listed.

Table 3. Dahlgren Polar Monitoring Service
NWL 9 Pole Report Revision

	Days 1977		Daily Solution (m) Pole Position X	Y	Standard Error X	Y	Bi-Daily (m) Solution X Y	Satellite	Nominal UT0-UT1
	333.	334.	2.58	1.11	.05	.05	.01-947058.66	1973 81A	244000.00
	334.	335.	3.46	2.48	.04	.05	.01-953246.60	1970-67A	247000.00
	335.	336.	4.21	1.12	.05	.05	.01-947058.66	1973 81A	250000.00
	336.	337.	3.00	2.30	.05	.06	.01-953246.60	1970-67A	254000.00
	337.	338.	2.72	1.74	.06	.05	.01-947058.66	1973 81A	258000.00
MEAN	336.		3.25	1.75	.05	.05			
STD DEV	336.		.66	.65	.00	.00			
STD ERR	336.		.30	.29					
	338.	339.	2.74	1.18	.05	.05	.01-953246.60	1970-67A	262000.00
	339.	340.	2.58	1.44	.05	.05	.01-947058.66	1973 81A	266000.00
	340.	341.	2.61	1.24	.05	.05	.01-953246.60	1970-67A	270000.00
	341.	342.	2.17	1.91	.05	.05	.01-947058.66	1973 81A	274000.00
	342.	343.	3.34	1.06	.05	.05	.01-953246.60	1970-67A	276000.00
MEAN	341.		2.69	1.36	.05	.05			
STD DEV	341.		.41	.33	.00	.00			
STD ERR	341.		.18	.15					
	343.	344.	1.63	.45	.06	.05	.01-947058.66	1973 81A	279000.00
	344.	345.	1.94	.52	.07	.06	.01-953246.60	1970-67A	282000.00
	345.	346.	2.06	.46	.05	.06	.01-947058.66	1973 81A	285000.00
	346.	347.	2.05	1.38	.05	.05	.01-953246.60	1970-67A	288000.00
	347.	348.	1.26	.51	.06	.05	.01-947058.66	1973 81A	290000.00
MEAN	346.		1.82	.66	.06	.05			
STD DEV	346.		.34	.40	.01	.00			
STD ERR	346.		.15	.18					
	348.	349.	2.29	1.99	.05	.05	.01-953246.60	1970-67A	294000.00
	349.	350.	1.40	.58	.05	.05	.01-947058.66	1973 81A	295000.00
	350.	351.	.81	.83	.05	.06	.01-953246.60	1970-67A	297000.00
	351.	352.	1.17	.77	.05	.05	.01-947058.66	1973 81A	299000.00
	352.	353.	1.52	.49	.05	.05	.01-953246.60	1970-67A	300000.00
MEAN	351.		1.45	.89	.05	.05			
STD DEV	351.		.56	.59	.00	.00			
STD ERR	351.		.25	.27					

POLE COORDINATE PLOTS

The motion of the pole during the years 1974 to 1977 may be seen at a glance in Figures 1 through 4. The most striking feature is the increase in amplitude, from about 3 to 8 m (half amplitude). It is simply a consequence of superposition of the 365.25- and 432-day components, out of phase in 1974, and in phase in 1977.

The Doppler data, now labelled DMA, are easily identified by their 1 error ellipses. These are the STD ERR of the five-day means shown in Table 3.

Also shown are the polar coordinates from three other sources, namely BIH, ILS, and IPMS. They are plotted as solid lines, dashes, and alternating dots and dashes, respectively. As in earlier years, the agreement between BIH and DMA is quite good. However, it must be pointed out that the Doppler data are used, in addition to optical observations, in deriving the BIH pole position results quoted for 1977. The agreement between IPMS and BIH or Doppler is reasonably good; the difference is 2 m only early in 1976, but usually much less. ILS, however, frequently differs from the other three determinations. The discrepancy reaches 3.5 m at several times. The total excursion of the pole, as shown by ILS, appears to be somewhat smaller than for the other three determinations.

The BIH path shown in Figure 4 appears exceedingly smooth. This is due to the fact that only "smoothed" data were available at the time the above plots were prepared. In the meantime, the 1977 Circular D "raw" data were acquired and used in Figure 5. It is believed to be more representative of the accuracy of the BIH five-day values.

Figures 6 to 13 permit a comparison of the various polar motion services separated into the X and Y coordinates. It may be seen that the differences are always larger in X than they are in Y. In fact, for 1974 through 1976 the agreement of all four services in Y is remarkably good. Note that again the smoothed BIH values were used in plotting Figures 9 and 13.

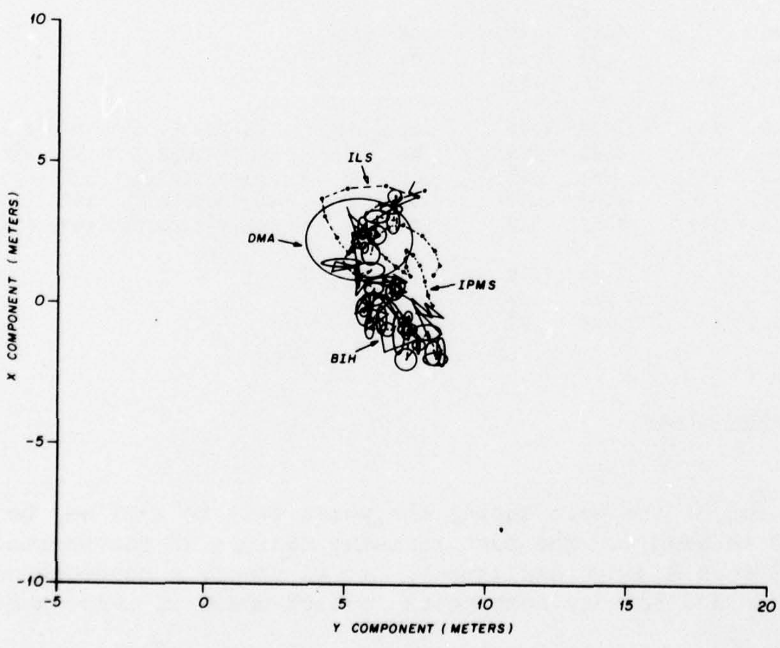

Figure 1. 1974 Pole Path

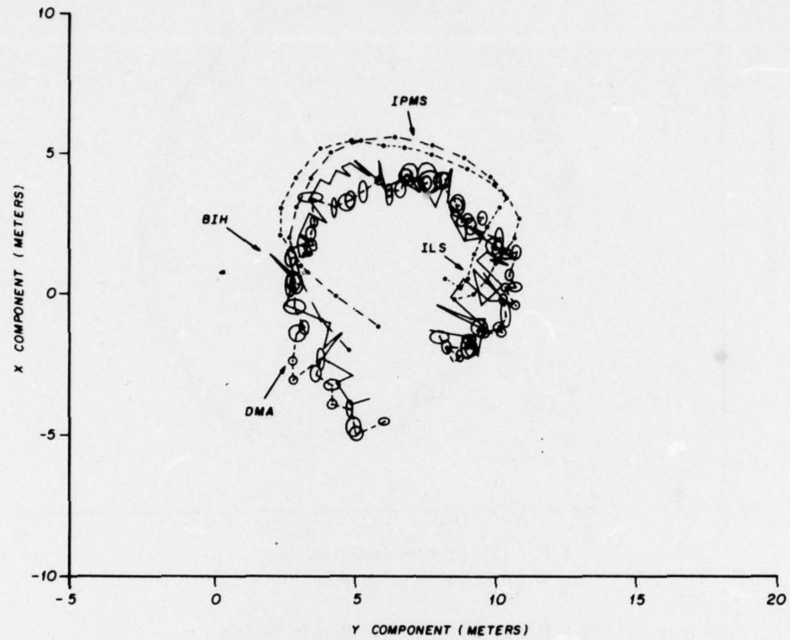

Figure 2. 1975 Pole Path

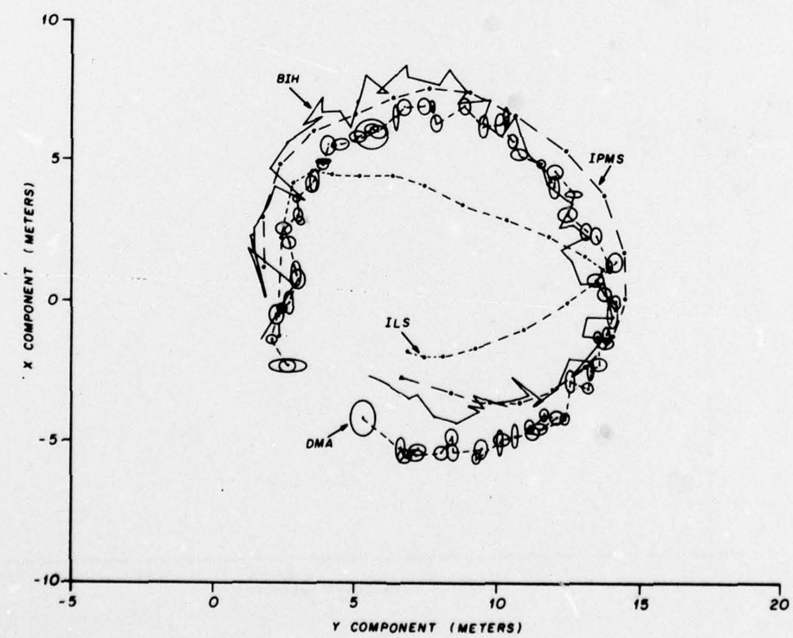

Figure 3. 1976 Pole Path

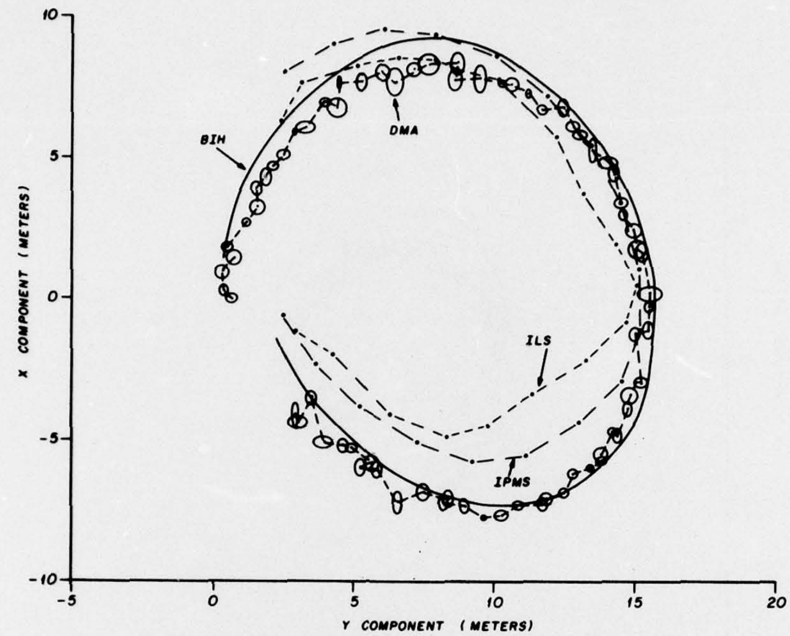

Figure 4. 1977 Pole Path

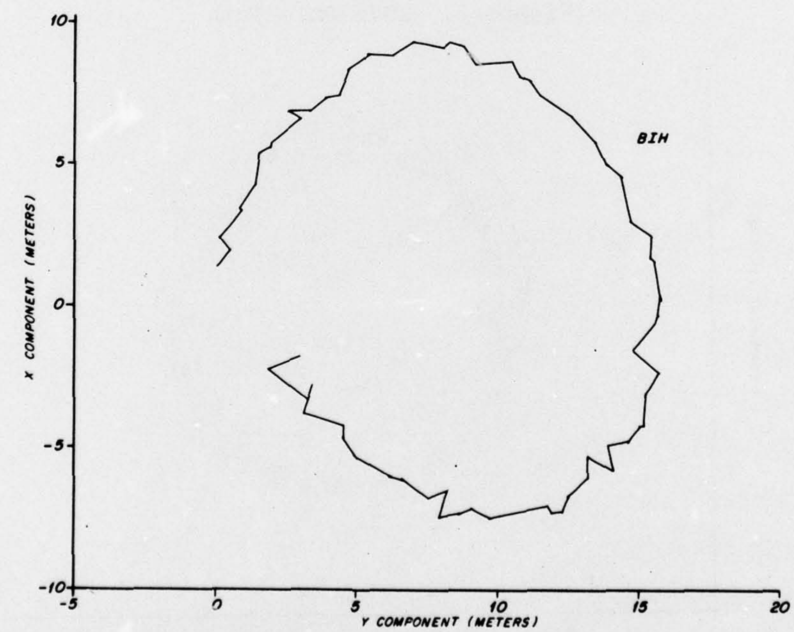

Figure 5. 1977 Pole Path

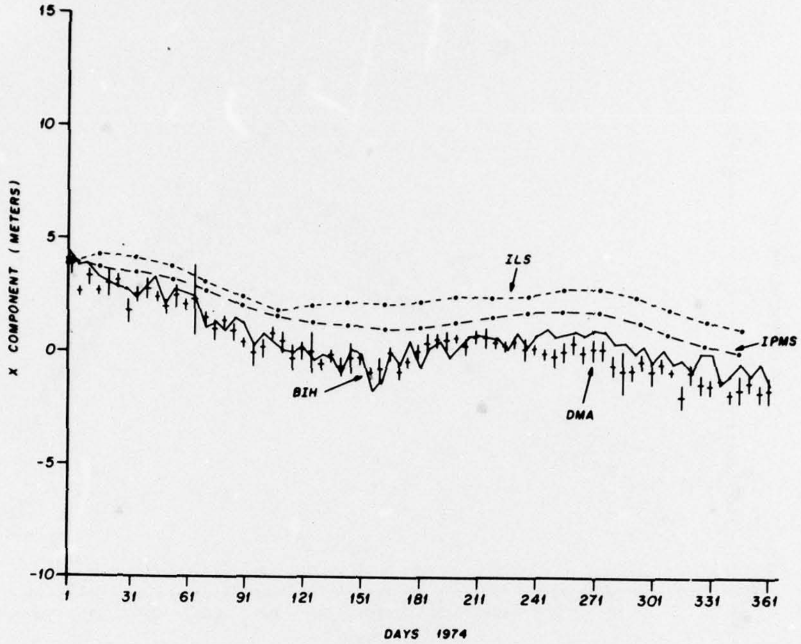

Figure 6. Pole Position for 1974, X Component

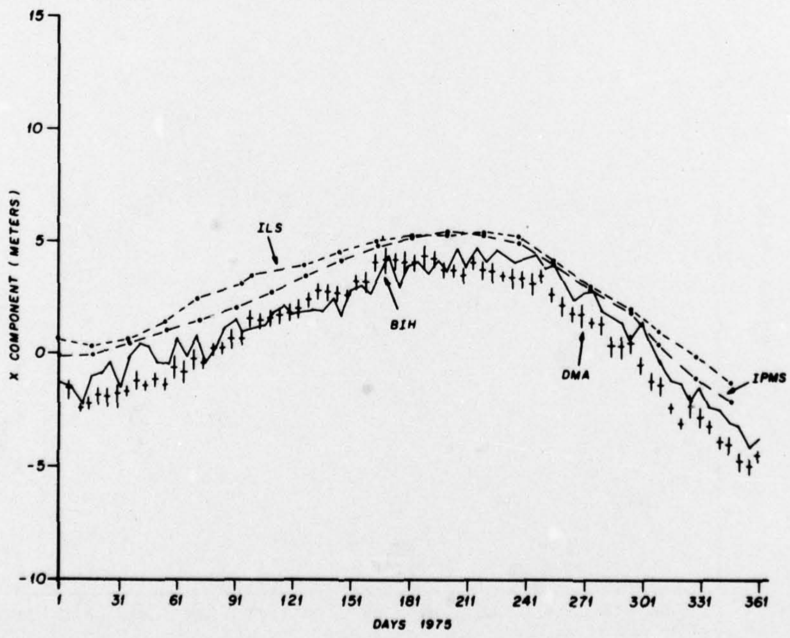

Figure 7. Pole Position for 1975, X Component

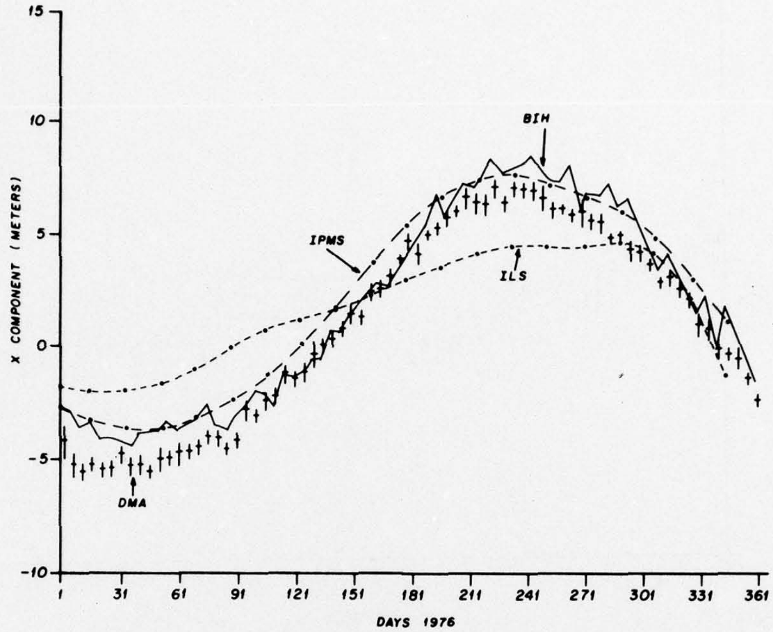

Figure 8. Pole Position for 1976, X Component

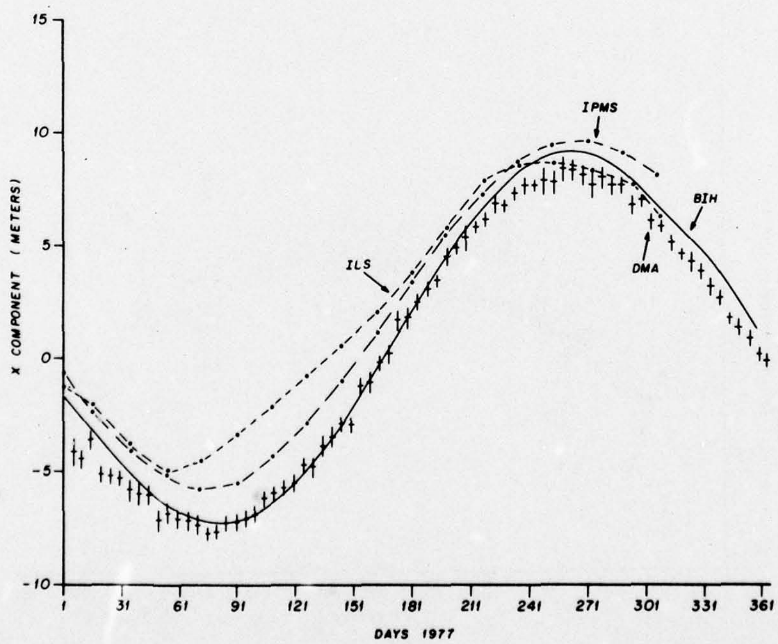

Figure 9. Pole Position for 1977, X Component

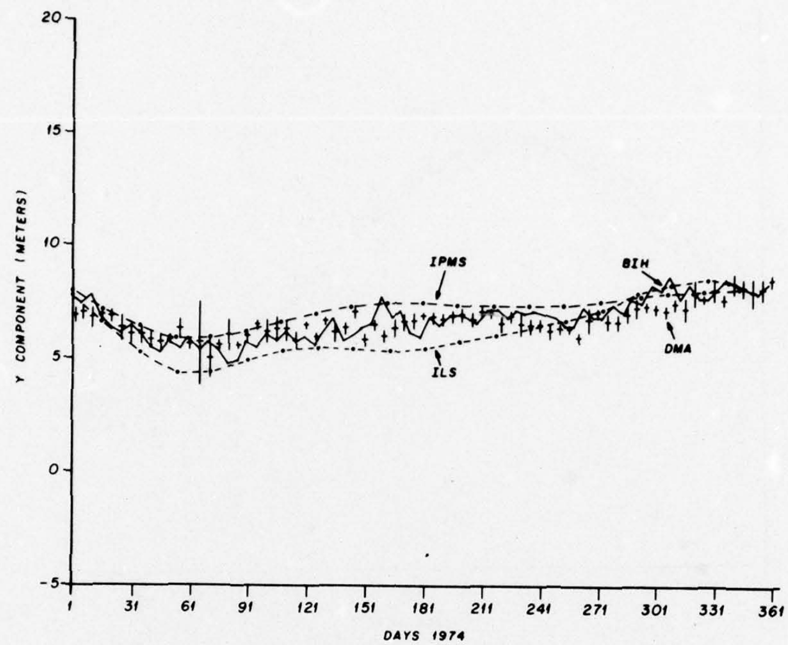

Figure 10. Pole Position for 1974, Y Component

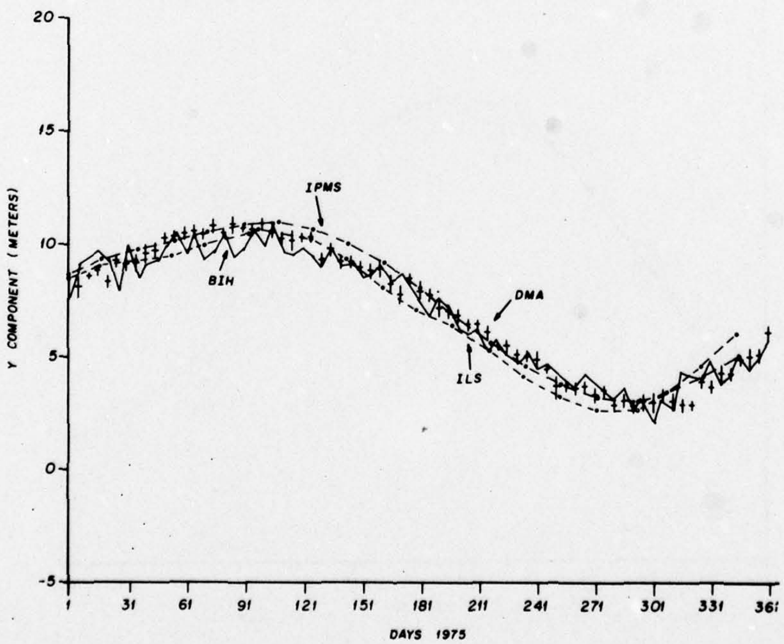

Figure 11. Pole Position for 1975, Y Component

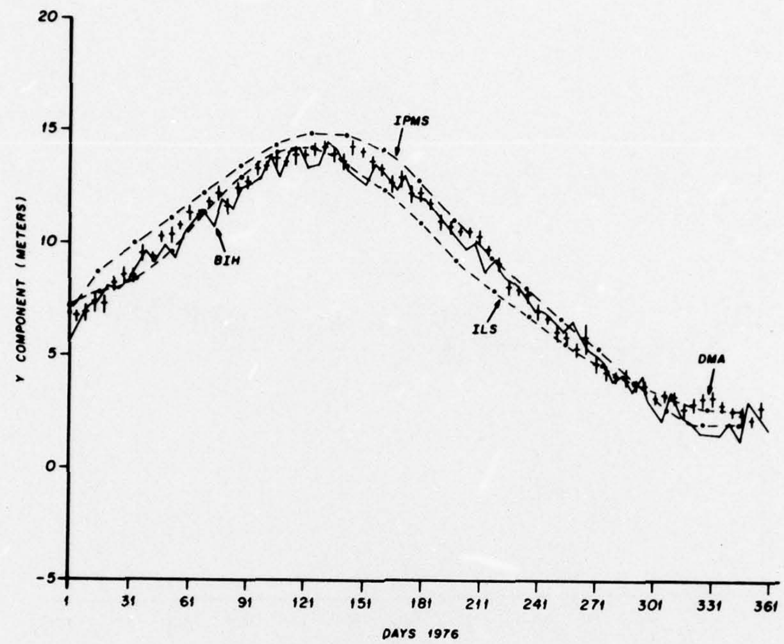

Figure 12. Pole Position for 1976, Y Component

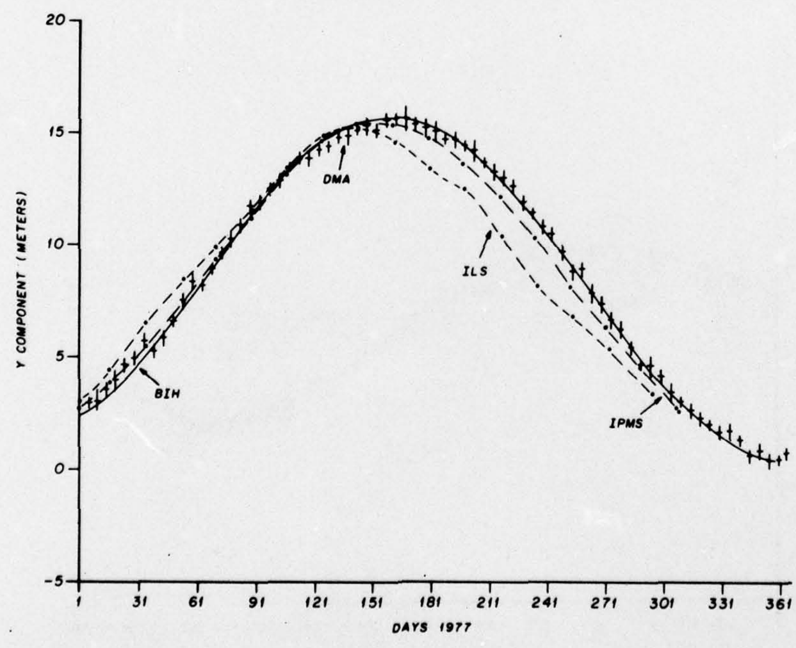

Figure 13. Pole Position for 1977, Y Component

DIFFERENCES IN POLE COORDINATES

Anderle (1976b) published plots of differences in the X and Y coordinates of the pole for the time spans 1964 through 1969 and 1970 through 1975. Similar plots, Figures 14 and 15, are given in this report for the interval 1974 through 1977. These diagrams show the differences in the four pairs BIH-ILS, DMA-ILS, DMA-BIH, and DMA-IPMS quite clearly. By and large, the Y-coordinates agree well, except for the ILS excursions in 1976 and 1977. In X, however, all four pairs show significant biases. ILS again shows some large variations with respect to BIH and DMA.

Tables 4 and 5 are a continuation of similar information published by Anderle in earlier reports. They list the yearly average difference for each of the four pairs being compared, as well as the standard deviation of the individual difference with respect to the annual mean. Individual points involving either ILS or IPMS would be 18 days apart, while DMA-BIH is formed every five days. Footnotes to Tables 4 and 5 contain additional information concerning data sources and reference frames.

THE CHANDLER PERIOD

It is well known that the principal periodic contents of the motion of the pole are the Chandler period and the annual term. In order to determine the former, Anderle (1977)* adapted an existing program to fit to the data an expression of the form

$$X_{comp} = X_o + A_s \sin\left(\frac{2\pi}{365.25}\right)t + A_c \cos\left(\frac{2\pi}{365.25}\right)t$$

$$+ C_s \sin\left(\frac{2\pi}{P_c}\right)t + C_c \cos\left(\frac{2\pi}{P_c}\right)t$$

and a similar equation for Y. P_c is the unknown Chandler period, and the X_o, A, and C are five numerical coefficients to be determined by least-squares fits. One assumes a value for P_c, obtains an expression for X_{comp} and Y_{comp}, and forms the residuals and their RMS. This is repeated for several values of P_c, and a parabola is fitted to three such pairs of points. Finally, one computes the value of P_c for which the rms parabola has its minimum. Obviously, to obtain P_c directly from a least-squares solution is more elegant, but the above procedure permitted the use of existing coding.

---

* Anderle, R. J., Naval Surface Weapons Center, Dahlgren Laboratory, Dahlgren, Virginia, office memo, 1977.

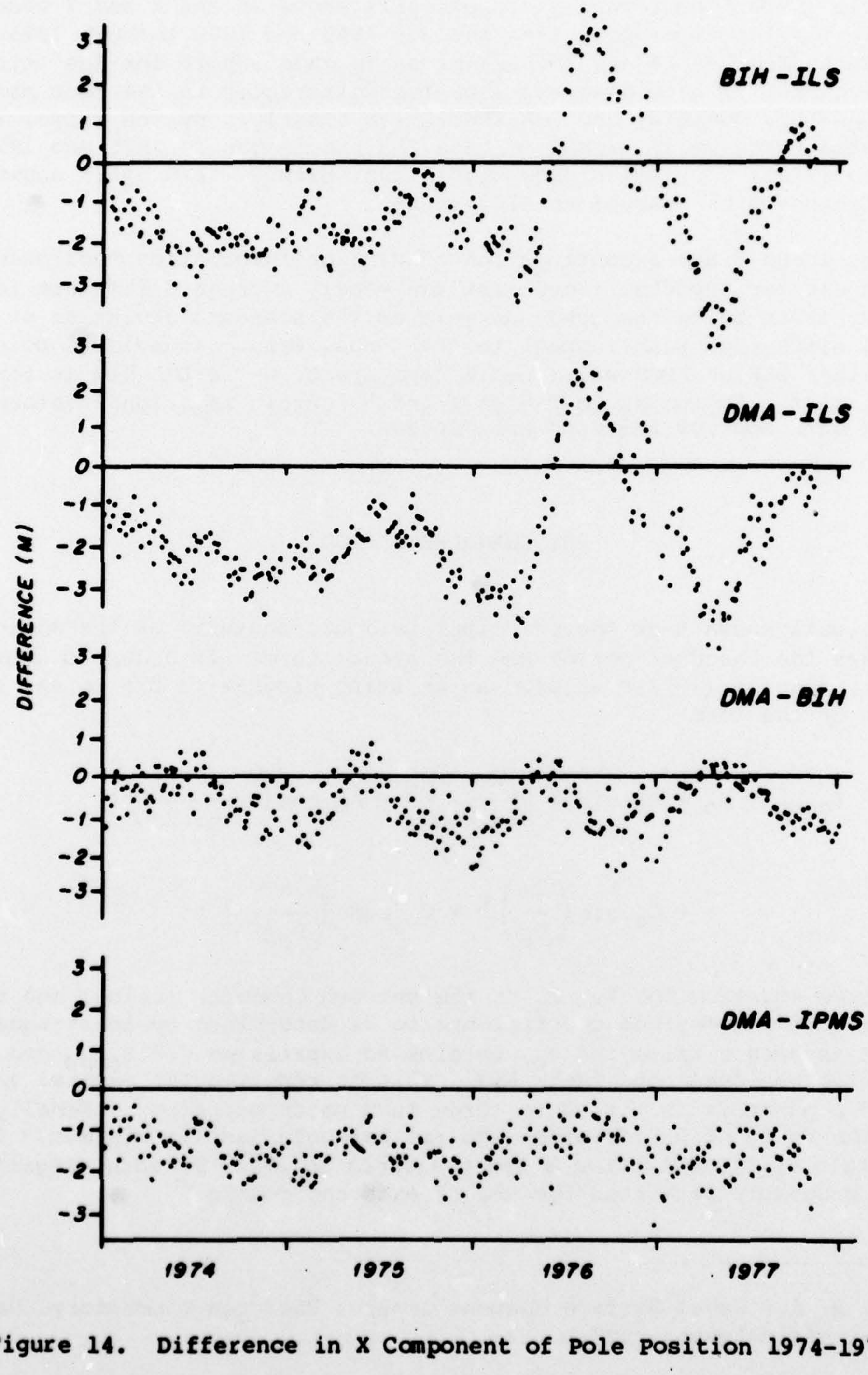

Figure 14. Difference in X Component of Pole Position 1974-1977

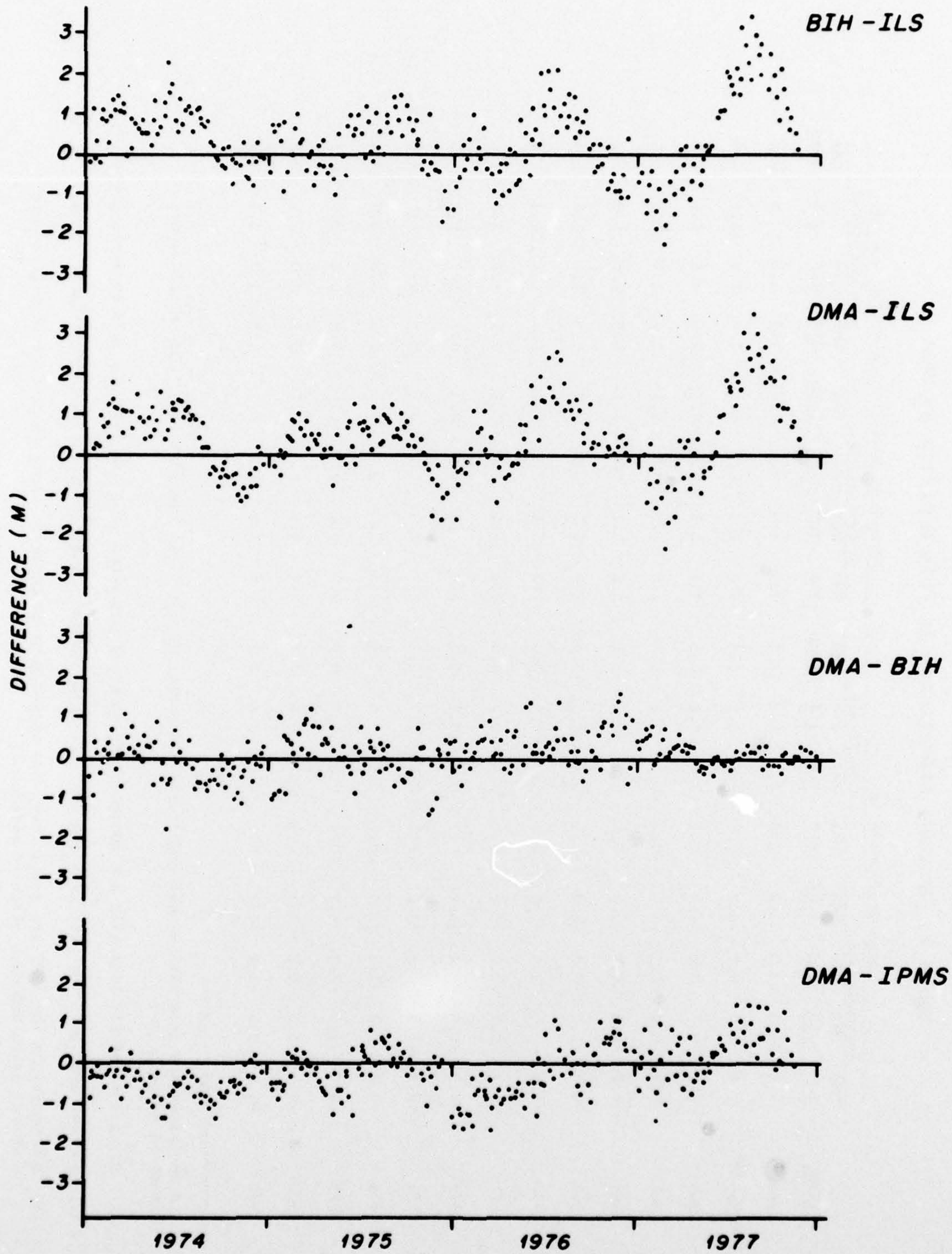

Figure 15. Difference in Y Component of Pole Position 1974-1977

Table 4. Average Differences in Pole Position By Year

	Mean Difference (m)								Standard Deviation of Difference (m)							
	X-Coordinate				Y-Coordinate				X-Coordinate				Y-Coordinate			
YEAR	DMA -BIH	DMA -ILS	BIH -ILS	DMA -IPMS	DMA -BIH	DMA -ILS	BIH -ILS	DMA -IPMS	DMA -BIH	DMA -ILS	BIH -ILS	DMA -IPMS	DMA -BIH	DMA -ILS	BIH -ILS	DMA -IPMS
1964 (1)	1.5	-0.5	-1.7	0.4	-0.0	0.3	0.8	0.2	1.9	1.4	1.1	1.8	1.4	1.5	1.0	1.5
1965 (1)	1.6	0.7	-0.8	0.9	0.8	0.8	0.1	0.9	0.8	1.1	0.5	0.8	0.9	1.6	0.8	1.5
1966 (1)	0.0	-0.7	-0.6	-0.9	0.1	0.7	0.1	0.1	0.5	1.3	0.8	0.5	0.6	0.6	0.9	0.8
1967 (1)	-0.5	-0.7	-0.2	-1.2	-0.3	-0.2	0.1	-0.5	1.9	1.8	0.9	1.9	1.4	1.9	1.0	1.5
1968	-0.7	-0.8	-0.2	-1.5	0.0	-0.4	-0.3	-0.1	1.8	1.1	1.0	1.1	1.5	1.3	0.9	1.2
1969	-0.3	-1.2	-0.8	-1.2	-0.1	-0.4	-0.3	-0.1	0.9	1.0	1.1	1.0	1.3	1.3	0.6	1.3
1970	-0.4	-1.1	-0.6	-1.4	0.3	-0.3	-0.5	0.0	1.0	0.8	0.8	0.8	1.0	1.1	0.8	1.4
1971	0.1	-0.7	-0.7	-0.8	-0.7	-0.9	-0.2	-0.9	0.8	1.6	1.5	1.2	0.9	1.4	1.3	1.6
1972	-0.3	-2.0	-1.4	-1.1	0.2	-0.2	-0.2	-0.7	1.0	0.9	0.9	0.7	0.7	0.9	0.8	1.0
1973	-0.3	-1.9	-1.5	-0.9	-0.2	0.0	0.2	-1.2	0.6	1.0	1.2	0.8	0.5	0.5	0.6	0.6
1974	-0.4	-2.2	-1.8	-1.4	-0.2	0.4	0.6	-0.6	0.5	0.7	0.7	0.5	0.5	0.8	0.7	0.4
1975	-0.7	-2.1	-1.4	-1.7	0.0	0.2	0.2	-0.3	0.7	0.6	0.7	0.5	0.6	0.6	0.7	0.5
1976 (3)	-0.9	-0.7	0.2	-1.3	0.3	0.5	0.2	-0.4	0.7	2.2	2.3	0.6	0.5	0.9	0.9	0.8
1977 (3) (4)	-0.6	-2.0	-1.6	-1.7	0.1	0.7	0.6	0.3	0.6	1.3	1.7	0.6	0.3	1.4	1.5	0.7

ILS Positions are from IPMS annual report and BIH positions are final raw positions from annual report except as noted below.

(1) BIH positions for 1964-1967 are smoothed astronomical positions given in 1969 and 1970 annual reports.

(3) ILS and IPMS positions for 1976 and 1977 are from the Monthly Notes of the IPMS (preliminary data).

(4) BIH positions for 1977 are preliminary raw values from Circular D. Note that these positions were computed using DMA data weighted solutions.

Table 5. Coordinate Systems and Gravity Fields

YEAR	COORDINATE SYSTEM	GRAVITY FIELD	DMA POLE POSITION
1964	NWL-9D	NWL-9B	NWL TR-2734, 2952 (9-Mean Positions)
1965	NWL-9D	NWL-9B	NWL TR-2734, 2952 (13-Mean Positions)
1966	NWL-9D	NWL-9B	NWL TR-2734, 2952 (6-Mean Positions)
1967	NWL-8D (5)	NWL-8B NWL-8D (20 Feb) (5)	Preprint (5)
1968	NWL-8F (19 Jan) (6)	NWL-9H (18 Apr) (6)	Preprint (6)
1969	NWL-8F (7,8)	NWL-8H (7,8)	NWL TR-2734 (7)
1970	NWL-9C (20 Dec)	NWL-9B (13 Feb)	NWL TR-2734
1971	NWL-9D (18 Oct)	NWL-9B (9)	NWL TR-2734
1972	NWL-9D	NWL-9B	NWL TR-2952
1973	NWL-9D	NWL-10E (2 Jan)	NWL TR-3181
1974	NWL-9D	NWL-10E	DMA Weekly Reports
1975	NWL-9D	NWL-10E	DMA Weekly Reports
1976	NWL-9D	NWL-10E	DMA Weekly Reports
1977	NWL-9Z-2 (15 June)	NWL-10E	DMA Weekly Reports

---

(5) Mean corrections of -2.06 and 1.48 m were added to 1967 NWL8D X- and Y-pole positions, respectively, based on comparisons with 12 NWL9D results given in TR-2734 and 2952.

(6) Mean corrections of -2.37 and 2.04 m were added to 1968 NWL9D X- and Y-pole positions, respectively, based on comparisons with 11 NWL9D results given in TR-2734 and 2952.

(7) Mean corrections of -0.07 and -2.35 m were added to 1969 NWL8D X- and Y-pole positions, respectively, based on comparisons with 12 NWL9D results given in TR-2734 and 2952.

(8) TR-2734 gives pole positions for 1969-1970 computed after adjusting NWL8F latitude residuals to NWL10D system

(9) DMA pole positions for 1964-1966 and after August 1971 are based on simultaneous solution for orbit constants and pole position rather than sequential solutions.

Figures 16 and 17 depict the curves discussed above. The legend shows that 12 years of data were used for the three astronomical sources, while only six years of Doppler data were available for this analysis. It can be seen that the astronomical services agree quite well. The minima are near 432 days, and they are well-defined. The Doppler X-coordinate curve is quite useless, and that for the Y-coordinate is of dubious value. It was quickly found that the short six-year time span is responsible. Solutions for the three astronomical sources over six years produced results comparable to the Doppler curves.

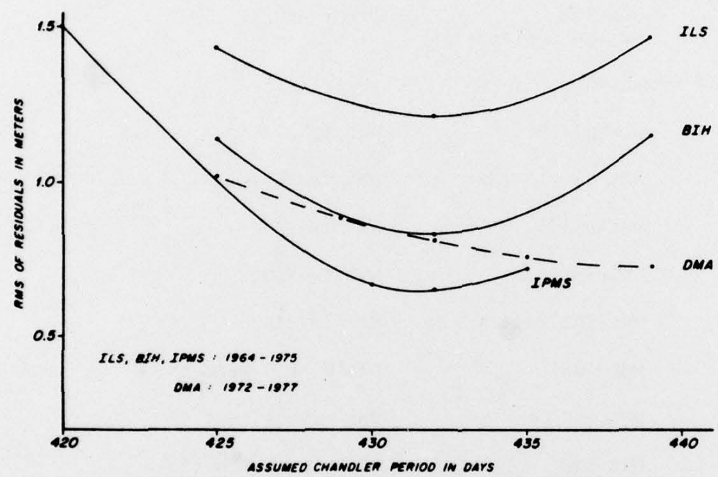

Figure 16. Residuals after 5-Parameter Fit X-Component

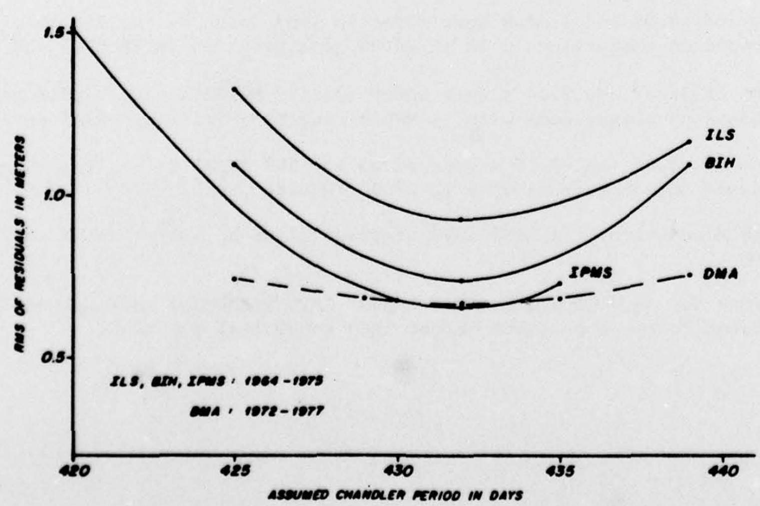

Figure 17. Residuals after 5-Parameter Fit Y-Component

Table 6 contains the results of the P_C computations explained above. In obtaining the averages and the mean value, unit weight was assumed. The error bound of 0.2 day was calculated from the scatter of the six individual values.

Table 6. Chandler Period *

P_C Days

	(X)	(Y)	
ILS	431.71	432.87	432.29
BIH	431.94	432.00	431.97
IPMS	431.77	431.79	431.78

* Mean Value: P_C = 432.0   0.2 days

Although of questionable value, P_C was also computed from the DMA Y-curve. It yields 432.2 days, in reasonable agreement with our adopted values of 432.0 days.

Our determination is also in good agreement with Markowitz (1976), who obtains 432.02   0.15 days. It compares reasonably well with Vicente and Currie (1976), who quote 433.2   0.8 days.

The above mentioned residuals are believed to contain other periodicities. Bowman and Leroy (1976), among others, have performed a spectral analysis of the X- and Y-components themselves, with the following results:

Table 7. Bowman/Leroy Spectral Analysis

Frequency (cycles/year)	Period (days)	Amplitude (m)	
0.85	430	5.84	0.6
1.0	365	4.84	0.6
1.3	280	0.49	0.6
2.0	180	0.23	0.6
2.5	145	0.12	0.6
4.0	90	0.11	0.6

Their analysis is based on five years of Doppler data. Considering our earlier difficulties with such a short time span, perhaps considerable strength could be added to the solution by including astronomical data. A particularly attractive time span would be 13 years, corresponding to almost exactly 11 Chandler cycles. However, reliable Doppler data does not yet exist for such an interval.

ADVANTAGES AND DISADVANTAGES OF DOPPLER

Doppler observations are taken day and night, and under any cloud cover. This all-weather capability is one of its major assets. Doppler data are also less sensitive to tropospheric effects than are optical observations. Moreover, they are independent of star catalog position errors. Perhaps Doppler's greatest value lies in the fact that it adds a totally independent pole position determination to the classical methods.

Systematic errors due to an inadequate knowledge of the gravity field is the major disadvantage of Doppler. Results are also affected by changes in the station network and atmospheric drag variations during a two-day span. Computing Doppler pole positions is quite expensive. At the present time, however, they are obtained as by-products in orbit improvement runs performed by DMA. Finally, although TRANSIT satellites have shown remarkable endurance, their life time is finite.

FUTURE PLANS

The planning of drag-free satellites is underway at the Applied Physics Laboratory, Johns Hopkins University. Once operational, effects due to drag would be eliminated and a better gravity field could be determined, resulting indirectly in better orbits and pole positions.

The earth gravity field is continuously being improved, especially by the National Aeronautics and Space Administration (NASA). NSWC has also begun work on a major new geodetic solution. Other improvements in the mathematical model are planned, especially better representations of the various tide effects.

SUMMARY

Computations of polar coordinates from Doppler observations have been performed in recent years by DMA. During the first half of 1977 as many as five satellites were observed. The standard deviation of a two-day polar coordinate solution is now better than 40 cm, that for the five-day mean under 20 cm. Agreement between the four services ranges from excellent to only fair. There are no significant problems in the Y-coordinate, except a 1.5 m standard deviation in 1977 for comparisons involving ILS. The X-coordinate shows both large biases and standard deviations.

It is found that six years of Doppler data are not enough to derive a reliable Chandler period. Hence, 12 years of data from the three astronomical services were taken to compute a Chandler period of 432.0 0.2 days. Residuals suggest the existence of additional periodic terms.

REFERENCES

Kershner, R. B., 1967, in "Practical Space Applications 21, Advances in the Astronautical Sciences," *American Astronautical Society, 41.*

Anderle, R. J., and L. K. Beuglass, 1970, "Doppler Satellite Observations of Polar Motion," *Bulletin Geodesique, 96, 125.*

Anderle, R. J., 1970, *Polar Motion Determinations by U. S. Navy Doppler Satellite Observations*, Naval Weapons Laboratory Technical Report, TR-2432, Dahlgren, Virginia.

Beuglass, L. K. and R. J. Anderle, 1972," Refined Doppler Satellite Determinations of the Earth's Polar Motion," in S. W. Henriksen, A. Mancini, B. H. Chovitz (eds.), "The Use of Artificial Satellites for Geodesy," *American Geophysical Union, Washington, D.C.*

Anderle, R. J., 1972, *Pole Position for 1971 Based on Doppler Satellite Observations*, Naval Weapons Laboratory Technical Report, TR-2734, Dahlgren, Virginia.

Anderle, R. J., 1973a, "Determination of Polar Motion from Satellite Observations," *Geophysical Surveys, 1, 147.*

Anderle, R. J., 1973b, *Pole Position for 1972 Based on Doppler Satellite Observations*," Naval Weapons Laboratory Report, TR-2952, Dahlgren, Virginia.

Beuglass, L. K., 1974, *Pole Position for 1973 Based on Doppler Satellite Observations*, Naval Surface Weapons Center/Dahlgren Laboratory, Technical Report TR-3181, Dahlgren, Virginia.

Anderle, R. J., 1976a, *Comparison of Doppler and Optical Pole Position over Twelve Years*, Naval Surface Weapons Center/Dahlgren Laboratory, Technical Report, TR-3464, Dahlgren, Virginia.

Anderle, R. J., 1976b, "Polar Motion Determined by Doppler Satellite Observations," *Bulletin Geodesique, 50, 377.*

Anderle, R. J., 1976c, "Polar Motion Determined by Doppler Satellite Observations," Presentation at Meeting of Commission 19 of the IAU, Grenoble, August 1976.

Bowman, B. R. and C. F. Leroy, 1976, "DMATC Doppler Determinations of Polar Motion," in "Satellite Doppler Positioning," Proceedings International Geodetic Symposium, October 1976.

Markowitz, William, 1976, *Comparison of ILS, IPMS, BIH, and Doppler Polar Motions with Theoretical*, Report to IAU Commissions 19 and 31, Grenoble, August 1976.

Vicente, R. O. and R. G. Currie, 1976, "Maximum Entropy Spectrum of Long-Period Polar Motion," *Geophysical J. R. Astr. Soc., 46, 67.*

REFERENCES (Continued)

Nouel, F., et. al., 1978, "Determination of Polar Motion by Doppler Tracking of Artificial Satellites," *GRGS MEDOC Bulletin*, January 1978.

DISTRIBUTION

Defense Documentation Center
Cameron Station
Alexandria, VA 22314 (12)

Library of Congress
Washington, DC 20540
Attn: Gift and Exchange Division (4)

National Aeronautics and Space Administraion
Scientific and Technical Information Facility
P. O. Box 5700
Bethesda, MD 20014
Attn: Technical Library (2)

Naval Electronics Systems Command
Department of the Navy
Washington, DC 20360
Attn: Technical Library

Director
Defense Mapping Agency
Washington, DC 20305

Director
Defense Mapping Agency
Hydrographic Center
Washington, DC 20390

Director, Defense Mapping Agency
Hydrographic/Topographic Center
6500 Brookes Lane
Washington, DC 20315
Attn: Dr. Randy Smith

Director
Defense Mapping Agency
Aerospace Center
St. Louis, MO 63118
Attn: Dr. Robert Ballew

Director
Naval Research Laboratory
Washington, DC 20360
Attn: Code 4130 (Mr. Roger Easton)
Code 7134 (Dr. K. Johnston)

DISTRIBUTION (Continued)

Deutsches Hydrographisches Inst.
Postfach 220
2000 Hamburg 4
Germany F. R.
Attn: Dr. H. Enslin

GRGS/CNES
18, Rue Edouard Belin
31055 Toulouse-Cedex
France
Attn: D. Gambis
Ing. F. Nouel

Tokyo Astronomical Observatory
Mitaka, Tokyo
181
Japan
Attn: Dr. S. Iijima

Cerga
8, Blbd. Emile Zola
06130 Grasse
France
Attn: Dr. J. Kovalevsky

Royal Greenwich Observatory
Herstmonceux Castle
Hailsham, Sussex BN27 1RP
England
Attn: L. V. Morrison
Dr. G. A. Wilkins

Observatorio De Marina
San Fernando (Cadiz)
Spain
Attn: A. Orte

Observatorire Royal De Belgique
Avenue Circulaire, 3
B-1180 Bruxelles
Belgium
Attn: Dr. P. E. G. Paquet

Earth Physics Branch D. E. M. R.
3 Obs. Crescent
Ottawa, Ontario, KIA OE4
Canada
Attn: Dr. J. Popelar

DISTRIBUTION (Continued)

U. S. Naval Academy
Annapolis, MD 21402
Attn: Technical Library

U. S. Naval Observatory
34th and Massachusetts Ave., NW
Washington, DC 20390
Attn: Dr. D. D. McCarthy

Jet Propulsion Laboratory
4800 Oak Grove Dr., Bldg. 264-747
Pasadena, CA 91103
Attn: Dr. W. G. Melbourne

Department of Geodetic Science
Ohio State University
Columbus, OH 43210
Attn: DR. I. I. Mueller

Department of Astronomy
University of Texas
Austin, TX 78712
Attn: Dr. J. D. Mulholland

Department of Aerospace Engineering
University of Texas at Austin
Austin, TX 78712
Attn: Dr. B. E. Schutz
Professor Dr. B. D. Tapley

Dr. D. E. Smith
13920 Blair Stone Lane
Silver Spring, MD 20906

Cerga/Roquevignon
Av. Nicolai Copernic
06130 Grasse
France
Attn: Dr. O. Calame

Observatoire De Paris
61, Av. De L'Observatoire
75014 Paris
France
Attn: Dr. S. Debarbat
Dr. M. Feissel
Dr. B. Guinot

DISTRIBUTION (Continued)

Department of Surveying and Geodesy
University of Oxford
62 Branbury Road Oxford OX2 6PN
England
Attn: Dr. A. R. Robbins

School of Physics
University of Newcastle
Newcastle upon Tyne NE1 7RU
England
Attn: Professor S. K. Runcorn

23 Normandale
Bexhill on Sea
East Sussex, IN39 3 LU
England
Attn: H. M. Smith

R. Mestre Aviz, 30, R/C
Lisbon 3
Portugal
Attn: Professor Dr. R. O. Vicente

Astronomisches Rechen-Institut
Monchhofstr. 12-14
D-6900 Heidelberg 1
Germany F. R.
Attn: Dr. H. G. Walter

Local:

E41	
K	
K10	(50)
K101	(50)
K11	(10)
K12	(10)
K13	(10)
X210	(2)
X2101 (GIDEP)	